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Climate policy vs. agricultural productivity shocks in a dynamic computable general equilibrium (CGE) modeling framework: The case of a developing economy

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ABSTRACT

The main objective of this paper is to compare the cost of climate policy consistent with the 2 °C global warming target (Paris Agreement target) with the cost of climate change induced agricultural productivity shocks, using a recursive dynamic CGE model for India. The social cost of carbon, in terms of loss in agriculture sector, is estimated to be about 2 percent of GDP, at zero rate of discount, under conservative forecasts of fall in agricultural productivity. In comparison, the cost of climate policy consistent with the Paris Agreement target of 2 °C is about 1 percent of GDP. Thus, there is a strong case for the adoption of ambitious climate policy in India, provided other countries also adhere to the same. Besides, revenues generated from the carbon tax and emission allowance could be a means to support the development and adoption of new energy and agricultural technologies, to increase social sector expenditure and to reduce abatement costs.

1. Introduction

There is growing concern around the world about the impact of rapidly rising levels of greenhouse gases (GHGs) on the environment and the economy. GHGs are primarily responsible for climate change (global warming) and they are closely linked to economic growth. The scientific evidence points to increasing risks of serious, irreversible impacts to the planet from climate change in business-*as*-usual (BAU) paths for GHG emissions (Stern, 2007). Further, there is an urgent need to bring down the level of emissions to scientifically acceptable levels since the costs associated with climate change are significantly higher than the costs of mitigation (Stern, 2007). The Paris Agreement (2015) recognizes the scientific view that the increase in average global temperature should be below 2 °C over the long term, in order to avoid catastrophic damages to the planet. Most countries of the world are signatories to the Paris Agreement, and many of these countries have pledged to reduce emissions though nationally set targets (Intended Nationally Determined Contribution or INDC).

Climate change is widely believed to be one of the biggest examples of market failure (negative externality) because the social cost of carbon emissions is not reflected by the private cost of emissions. Therefore, the market outcome is not efficient and emissions are far above the optimal level. The problem is compounded further if emissions are mainly the result of subsidized energy consumption, as in many countries. Subsidized energy not only leads to higher emissions but also limits the level of public expenditure on the social sector. For example, in India cash subsidies to firms engaged in the marketing of petroleum products was about 1.07 percent of GDP in 2010–11, while public expenditure on health and education were only 1.27 and 2.98 percent of GDP, respectively (TERI and IISD, 2012). Market based instruments are increasingly being used by developing countries like India to address market distortions caused by subsidized energy. For example subsidies on many petroleum products have been abolished or reduced, and a tax on coal production (Clean Environment Cess) has been implemented in India.

There is considerable debate in the literature regarding the nature and costs of climate change, what actions should be taken to counter it, and how fast those actions need to be taken (Nordhaus, 2007). According to Stern (2007) the total cost (market and non-market) of climate change

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assuming 3.9 °C average warming relative to the pre-industrial level is the equivalent of about 20 percent reduction in current per capita consumption, now and forever. A similar study by Nordhaus and Boyer (2000) has reported a cost of 9–11 percent of global GDP at 6 °C warming. Nordhaus (2007) has pointed out that the relatively high estimates of damages obtained by Stern (2007) are due to the assumption of a near zero time discount rate by Stern (2007). Weitzman (2009) on the other hand argues that the economic consequences of low probability, high impact catastrophes like climate change can outweigh the effects of discounting in climate policy analysis. In case of India the average cost is estimated to be 6 percent of GDP by 2100, compared with a global average of 2.6 percent, assuming average warming of 3.9 °C above the pre-industrial level (Stern, 2007).

The effects of climate change on agriculture is of particular significance for India given that agriculture (and allied sectors) accounted for about 15 percent of GDP, and about 63 percent of rural male workers and 79 percent of rural female workers are engaged in this sector (Ministry of Statistics and Programme Implementation, Government of India, 2011b). Indian agriculture is particularly vulnerable to climate change because it is mostly rain fed. This paper attempts to compare the economic cost of agricultural productivity loss due to projected climate change with the cost of climate change mitigation policy consistent with the Paris Agreement target for India. By doing so the paper tries to answer the crucial question - is there a case for the implementation of ambitious climate policy in India? Towards finding an answer to this question the implications of agricultural productivity shocks and climate policies, in terms of growth and welfare, are analyzed explicitly in this paper. Specifically, this paper tries to understand the mechanisms through which productivity shocks and climate policies affect growth and welfare across different household groups. Our study differs from the study by Stern (2007) both in terms of data and model - we use more disaggregated data (Social Accounting Matrix for India) and a recursive type model, instead of a forward looking model.

The rest of the paper proceeds as follows. In the next section (Section 2) we broadly discuss the literature on climate change impact on agriculture and climate change mitigation policies, followed by presentation of the model and data in Section 3. In Section 4, the different simulations conducted to address the objectives of the paper are described, while Section 5 presents the results. Finally, in Section 6, the conclusions and policy implications are outlined.

2. Literature review

The effects of climate change are likely to be severe for developing countries. Developing countries are at a geographic disadvantage because they are already warmer, on average, than developed countries, and they also suffer from high rainfall variability. Second, developing countries are heavily dependent on agriculture, the most climate-sensitive of all economic sectors, and third, their low incomes and vulnerabilities make adaptation to climate change particularly difficult (Stern, 2007).

There exists a wide body of literature on estimates of climate change impacts on agriculture. Hertel et al. (2010) explore the impacts of adverse climate change on different segments of the population living on $1/day across a sample of 15 developing countries. Under their adverse climate scenario for 2030 (5 percent probability of occurrence), global staple grain prices rise by 10–60 percent, and agricultural returns rise sharply in most regions. Average poverty rates fall in the agricultural specialized households, as well as in the diversified households, while the average poverty headcount rises for rural and urban wage labor households, non-farm self-employed and transfer payment dependent households. In the “high productivity” scenario for 2030 (5 percent probability of occurrence) in which world prices fall due to climate change, poverty fall for urban and wage earning households, and rise for agricultural households. In the most likely climate change scenario for 2030 there is little change in world prices due to modest productivity effects and offsetting impacts in northern (higher yields) and tropical (lower yields) latitudes and therefore poverty impacts are lower.

According to IPCC (2007), temperature will increase by 0.5–1.2 °C by 2020, 0.88–3.16 °C by 2050 and by 1.56–5.44 °C by 2080, in South Asia. Increase in temperature will cause shifts in crop growing seasons, increase the incidence of pests and diseases and lower agricultural productivity. Several studies (Table 1) have estimated the impact of climate change on agricultural productivity in South Asia/India, and the estimates vary quite a bit. Cline (2007) has reported that agricultural productivity in India could decrease by 30–40 percent by the 2080s due to climate change. According to IFPRI (2009), average yields in 2050 could decrease from 2000 levels by about 50 percent in case of wheat, 17 percent in case of rice and about 6 percent in case of maize, while Nelson et al. (2010) report that productivity of rice and wheat are likely to decrease while productivity of maize, millet and sorghum are likely to stay constant or increase due to the effects of climate change. A recent study by the National Initiative for Climate Resilient Agriculture (NICRA) projects agricultural yield reduction of 4.5–9 percent for the period 2010–39, depending on magnitude and distribution of warming. Auffhammer et al. (2011) find that rice yields in India would be 1.7 percent higher on average if the monsoon pattern had not changed since 1960, and an additional four percent higher if two further meteorological changes, warmer nights and less precipitation at the end of the growing season, had not occurred. The individual effect of increasing minimum temperatures is reported at 3.4 percent; this caused more than half of the total yield decline. Accordingly, the results indicate that average yield in India could have been almost six percent higher (75 million tons in absolute terms) without changing climatic conditions and confirm that increasing minimum temperatures have had a greater impact on yield than changing monsoon characteristics. The analysis does not account for adaptive responses by farmers. Lin and Huybers (2012) show that wheat crop yields peaked in India and Bangladesh around 2001 and have not increased despite increasing fertilizer applications, while Kalra et al. (2008) explain, using a crop growth model, the wheat yield stagnation in most parts of northwest India through the interactions of radiation and temperature change. Further, Rosenzweig and Binswanger (1993) report that a delay in the onset of the monsoons in rural villages in India by just one standard deviation can reduce agricultural profits for the poorest households by more than one-third.

Zhai and Zhuang (2009) report that with the anticipated decline in

Table 1
Some estimates of climate change impact on agriculture for South Asia/India.

Study	Sector/Region	Estimate of climate change impact
Cline (2007)	Agriculture (India)	Productivity decrease by 30–40 percent by the 2080s
IFPRI (2009)	Wheat (South Asia/India)	Average yield decrease by about 50 percent (2000–2050)
IFPRI (2009)	Rice (South Asia/India)	Average yield decrease by about 17 percent (2000–2050)
IFPRI (2009)	Maize (South Asia/India)	Average yield decrease by about 6 percent (2000–2050)
Nelson et al. (2010)	Rice (South Asia)	Average annual yield change −0.2 percent till 2050
Nelson et al. (2010)	Wheat (South Asia)	Average annual yield change −1.3 percent till 2050
Nelson et al. (2010)	Maize (South Asia)	Average annual yield change 0.1 percent till 2050
Nelson et al. (2010)	Millet (South Asia)	Average annual yield change 0.0 percent till 2050
Nelson et al. (2010)	Sorghum (South Asia)	Average annual yield change 1.4 percent till 2050
National Initiative for Climate Resilient Agriculture (NICRA)	Agriculture (India)	Yield reduction of 4.5–9 percent (2010–39)

agriculture share of GDP, the aggregate output losses from climate change-related agricultural productivity reduction would be modest for most Southeast Asian countries. However, import dependence on crop products would rise for Southeast Asia in the coming decades. This increasing exposure to world agricultural markets would make Southeast Asian economies suffer more welfare losses through the deterioration of terms of trade. This effect is especially significant for Malaysia and Singapore. Further, Oktiaviani et al. (2011) assess climate change impacts for Indonesia using an Indonesian computable general equilibrium (CGE) model that focuses on the agricultural sector. The study finds that by 2030 global climate change will have a significant and negative effect on the Indonesian economy as a whole, and especially for the agricultural sector (both producers and consumers) and in rural areas and for poorer households. Real gross domestic product (GDP) drops slightly and the consumer price index (CPI) increases by a small amount in the study. Negative GDP growth is chiefly the result of adverse impacts on agriculture and agro-based industries, with the largest impact for soybeans, rice, and paddy (un-milled rice). The study concludes that decreasing output of paddy and rice will adversely affect the country's food security and addressing constraints to agricultural productivity growth through increased public agricultural research investments is crucial to counteract the adverse impacts of climate change.

Thus, the literature points out that climate change has had an adverse impact on agricultural productivity in Asia/India, and the impact is likely to increase in the future unless suitable measures are implemented. Global climate agreements, such as the Paris Agreement (2015) that aim to reduce global emissions and warming are thus crucial in this context. Table 1 presents estimates of climate change impacts on agriculture for South Asia/India. .

Climate change mitigation policies (such as carbon taxes) have been widely used to achieve environmental objectives, although their application in the Indian context has been limited. Numerous studies have been conducted to analyze the effects of such policies on the environment as well as the economy in general, and we present some of the key findings in the following paras. Using a global model Davies et al. (2011) find that global carbon pricing consistent with a long term 2 °C global warming target can yield revenues which are large enough to reduce global inequality and poverty. However, Tian and Whalley (2010) conclude that differences in damage estimates, emission intensity etc could make it difficult to achieve global consensus on emission reduction in the post Copenhagen regime. In this context the Paris Agreement (2015) is a significant milestone. Garbaccio et al. (1998) have examined the use of carbon taxes to reduce CO_2 emissions in China and have found that a ‘double dividend’, that is,lower CO_2 emissions and a long-run increase in GDP and consumption could be achieved under assumptions of inelastic labour supply and revenue-neutral taxes.

In India specific studies similar results as above have been obtained by different authors. Fisher-Vanden et al. (1997) have reported that under an equal per capita emissions allocation scheme India would benefit absolutely from participation in a global tradable permits market, but economic growth would be slowed under the Grandfathered emissions allocation scheme. Weitzel et al., 2014 find that international prices of fossil fuels influence the income distribution effects of climate change mitigation policies in India. Further, Pradhan et al. (2017) report that rate of deployment of new energy technologies could influence abatement 1`costs in China and India.

Thus, one of the main conclusions that one can derive from the above discussion is that both climate change and climate policies could have significant economy-wide impacts in India, and these impacts are likely to be heterogeneous across different population groups both in terms of magnitude and direction. For example, climate change impacts such as agricultural productivity loss will predominantly affect rural agricultural households, while climate policies such as carbon taxes could have a much wider impact. As mentioned earlier we try to compare the cost of climate change with the cost of climate policy using a recursive dynamic CGE model for India.

3. Model and data

Our model (Pradhan and Ghosh, 2012a; see Appendix D for model equations) is a single country, multi-sectoral, neo classical type price driven recursive dynamic CGE model with features that capture linkages with the energy system. The model shares many of its features with energy/climate policy related CGE models like DART (Klepper et al., 2003), EPPA (Paltsev et al., 2005) and EMPAX-CGE (RTI International, 2008). The basic structure of our model is based on Lofgren et al. (2002). Our model consists of eighteen sectors - Agriculture, Coal, Oil, Gas, Manufacturing I (food and beverages, textiles, wood, minerals), Manufacturing II (paper, fertilizers, cement, iron and steel, aluminum, chemicals), Manufacturing III (plant and machinery), Oil Products, six Electricity sectors (Thermal, Carbon Capture and Storage (CCS), Hydro, Nuclear, Biomass and Other Renewables), Construction, Road Transport, Rail/Sea/Air transport, and Other Services. There are two factors of production, capital and labor. Land is not taken as a separate factor of production because of data issues (SAM does not distinguish different types of capital). It may also be noted that agricultural capital refers to land mainly. Further, a substantial amount of agricultural land will go for non-agricultural use in future (though this is a one way mobility).

In line with standard CGE assumptions producers are assumed to maximize profits and to operate in perfectly competitive markets. The production structure of the fossil fuel sectors (Coal, Oil, and Gas) and the non-fossil fuel sectors (sectors other than Coal, Oil, and Gas) are modeled differently. The production structure of the fossil fuel sectors takes into account the limited availability of fossil fuels in the economy by fixing part of the capital of these sectors, while in case of the non-fossil fuel sectors this feature is not relevant and therefore not modeled. In case of the fossil fuel sectors (Appendix C - Fig. C.1), the top nest is a CES aggregation of capital–labor–aggregate intermediate input composite and the fixed fossil fuel resource (part of capital of the sector). The capital–labor–aggregate intermediate composite is a Leontief function of the capital–labor composite and aggregate intermediate input. The capital–labor composite (aggregate value added) is in turn a CES aggregation of capital and labor.

In case of the non-fossil fuel sectors (Appendix C - Fig. C.2), the top nest is a Leontief function of aggregate intermediate input and energy–capital–labor composite. The energy–capital–labor composite is a CES function of the energy composite and the capital–labor composite. The energy composite is a CES function of the non-electric composite and the electric composite. The non-electric composite is a CES aggregation of Coal, Oil, Gas, and Oil Products. The electric composite is a CES aggregation of renewable electricity composite and non-renewable electricity composite. The renewable electricity composite is a CES aggregation of Hydro, Nuclear, Biomass and Other Renewables electricity, while the non-renewable electricity composite is a CES aggregation of Thermal and CCS electricity. The capital–labor composite is a CES function of capital and labor. The aggregate intermediate input is a Leontief function of intermediate inputs. The main features of the production structure of the non-fossil fuel sectors are the substitution possibilities between energy, capital, and labor on one hand and the substitution possibilities between renewable and non-renewable sources of electricity on the other.

Households maximize utility subject to income and prices, and the household demand for commodities is modeled through the linear expenditure system (LES). Household income comprises of income derived from labor and capital and transfers from the government and the rest of the world. Households also save part of their income and pay taxes to the government. Further, households are classified into nine categories: five are rural (Self Employed in Non-Agriculture, Agricultural Labor, Other Labor, Self Employed in Agriculture and Other Households) and four are urban (Self Employed, Regular Salaried, Casual Labor, and Other Households).

Government expenditure is on the consumption of goods and services, transfers to households and enterprises, and subsidies. Government

income is from taxes (direct and indirect), capital, public and private enterprises, and rest of the world. Indirect taxes include excise duty (production tax), import and export tariffs, sales, stamp, service, and other indirect taxes. Government savings which is the difference between government expenditure and income is determined residually.

Imperfect substitution between domestic goods and foreign goods is allowed for in CGE models. In other words, producers/consumers are free to sell or buy the same goods from the domestic or foreign market based on relative prices. The Armington function is used to capture these substitution possibilities between domestic and imported goods. The import demand function, derived from the Armington function, specifies the value of imports based on the ratio of domestic and import prices. The CET function is used to capture substitution possibilities between domestic and foreign sales. The export supply function, derived from the CET function, specifies the value of exports based on the ratio of domestic prices to export prices. The elasticity of substitution determines the relative ease of substitution between domestic and foreign goods in response to changes in relative prices.

The model is Walrasian in character. Markets for all commodities and factors clear through adjustment in prices. The consumer price index (CPI) is chosen as the numeraire. Macro closures play an important role in CGE models and they are specified taking into account the macro economic reality of the country/region being modeled. Our model follows an investment-driven closure, that is, aggregate investment is fixed in the Keynesian tradition. The saving-investment balance is maintained through adjustment in aggregate savings (sum of household, government, corporate and foreign savings). The model assumes foreign savings to be fixed and the real exchange rate to be flexible. Government consumption expenditure is fixed within a period, and government savings is residually determined. Both direct and indirect tax rates are fixed. The household savings rate is also fixed. Finally, full employment along with inter-sectoral mobility is assumed in case of both the factors of production.

The baseline ('business as usual' or 'BAU') scenario is created by assuming exogenously determined growth in total factor productivity (TFP), labor force, government consumption expenditure and aggregate investment. Capital is augmented by adding aggregate investment in the previous period to capital. In order to capture future increases in energy efficiency, an energy efficiency growth rate is assumed. Future technological developments in the renewable electricity sectors (Hydro, Nuclear, Biomass, and Other Renewables) are modeled by assuming efficiency growth in these sectors. Changes in international prices (exogenous) of fossil fuels are modeled keeping in view future price projections of these commodities. The time horizon is till 2050, and the model is solved using the GAMS software (PATH solver).

The main source of data for the analysis is a social accounting matrix (SAM) for 2003–04 developed by Ojha et al. (2009). This SAM, in turn, is based on the SAM constructed by Pradhan et al. (2006). The main difference between the two SAMs is the decomposition of the electricity sector into three sub-sectors - hydro, nuclear, and non-hydro - in the SAM constructed by Ojha et al. (2009). The non-hydro energy sector includes thermal, wind and solar electricity. However, given India's energy mix, thermal electricity is the main constituent of this group. Two modifications were made in the non-hydro sector for the purpose of this study. The first modification pertains to the disaggregation of non-hydro into Thermal and Other Renewables electricity. The second modification pertains to the creation of a sector (from Thermal) that uses CCS technology (coal) to produce electricity. The CCS electricity sector is assumed to be similar to the Thermal electricity sector but less efficient. It produces electricity using clean coal (no emissions), although at a much higher cost.

4. Scenarios

Initially a baseline scenario ('BAU' scenario) is created by assuming a GDP growth rate of 6.9 percent over the time horizon (2004–50). This growth rate is consistent with current trends. The BAU scenario does not consider climate change impacts or climate policy. Further, three simulations (see Table 2) were run to compare the economic impacts of different levels of agricultural productivity loss, and one scenario was run to assess the economic impact of climate policy consistent with the 2 °C global warming target. The agricultural productivity loss scenarios are based on projections by the National Initiative on Climate Resilient Agriculture (NICRA). According to NICRA there could be agricultural yield reduction of 4.5–9 percent for the period 2010–39 in India, depending on magnitude and distribution of warming. We select the NICRA projections for three reasons – first, the projections are for the agriculture sector as a whole, thus making them straightforward for incorporation into our model. Second, the time horizon (2010–39) is large enough to be consistent with our modeling framework (2004–50), and third, NICRA is a government agency which gives the projections higher credibility from a decision making perspective. In the first simulation (SIM 1) we simulate the impact of 4.5 percent reduction in agricultural yield loss between 2010 and 2039. In the second simulation (SIM 2) we simulate the impact of 9 percent reduction in agricultural yield loss between 2010 and 2039, while in the third simulation (SIM 3) we simulate the impact of the same yield reduction (9 percent) over a shorter time horizon that is between 2010 and 2024. In the final simulation (SIM 4) we simulate the impact of climate policy (global cap and trade type system) consistent with the 2 °C global warming target. The data (carbon prices and CO_2 emission allowances; see Appendix B) required to implement the climate policy scenario were obtained from a global climate model (see Johansson et al., 2015 for a detailed discussion). The global emissions pathway in the global climate model is implemented through a cap and trade system in which the distribution of emission permits is based on the Common but Differentiated Convergence (CDC) Approach (Hohne et al., 2006). The CDC approach aims at equal per capita allowances in the long run, and takes into account historical responsibility. In the CDC regime international capital flows take place as a result of trade in emission permits between countries. In our model international capital flows as a result of trade in emission permits are modeled as bridging foreign deficit gaps (in India). The climate policy scenario is modeled from 2013 onwards keeping in view a Post Kyoto global climate regime. In our model the carbon tax is applied on the consumption of Coal, Gas and Oil Products, because the consumption of these products is directly linked to CO_2 emissions.

Table 2
Scenario descriptions.

Scenario	Description	Source/Rationale
SIM 1	4.5 percent reduction in agricultural yield between 2010 and 2039	Based on NICRA lower bound estimate
SIM 2	9 percent reduction in agricultural yield between 2010 and 2039	Based on NICRA upper bound estimate
SIM 3	9 percent reduction in agricultural yield between 2010 and 2024	NICRA upper bound estimate over shorter time period (half the time period) – extreme case scenario constructed by authors
SIM 4	Climate policy (global emissions trading consistent with the Paris Agreement 2 °C global warming target)	Carbon prices and emission allowances obtained from global climate CGE model (DART) in view of a Post Kyoto regime

5. Results

In this section we discuss the growth and welfare impacts observed in the different scenarios described above. The growth impacts are presented in Fig. 1 while welfare effects are presented in Figs. 2–5. There is contraction in GDP growth relative to BAU in all the scenarios, with the highest being 0.26 percentage points in SIM 3 (agricultural productivity loss higher than NICRA projections) and the lowest being 0.06

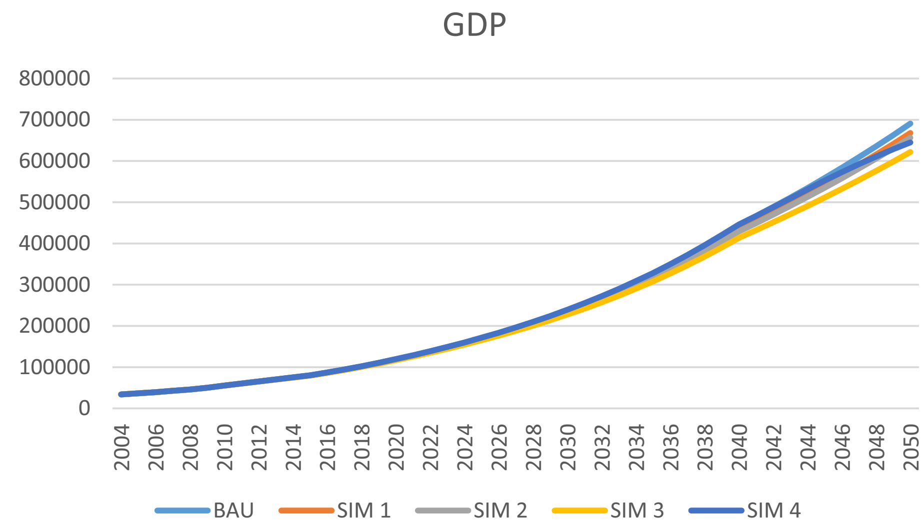

Fig. 1. GDP impact in the different scenarios (billion rupees).
Source: Authors' estimates

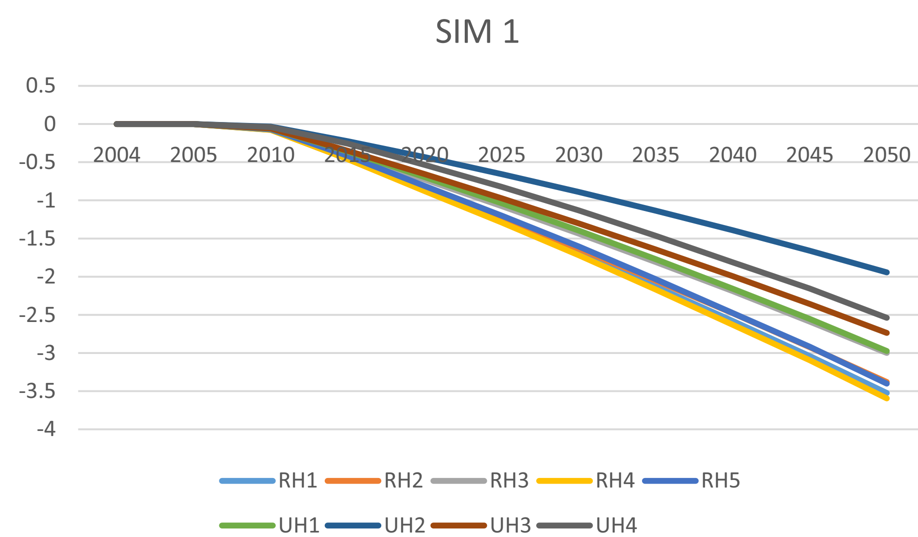

Fig. 2. Welfare impact (equivalent variation percent) for different household groups in SIM 1.
Source: Authors' estimates

percentage points in SIM 4 (climate policy scenario consistent with 2 °C target). Further, it is observed that GDP contraction is higher in the productivity shock scenarios compared to the climate policy scenario. GDP contraction is driven by lower demand in the economy. Fig. 1 shows that GDP impact is modest in most scenarios till the 2040's implying that the costs of both climate change impact on agriculture and climate policy are likely to be modest over the long run. In this context Zhai and Zhuang (2009) also report that aggregate output losses from climate change-related agricultural productivity reduction would be modest for most Southeast Asian countries. Only in SIM 4 (extreme agricultural productivity loss scenario) where productivity shocks are the strongest GDP loss occurs from the mid 2020's itself. In the presence of climate policy regime (SIM 4) and negligible climate change impact GDP loss is likely to be minimal. In other words SIM 4 assumes that climate policy is fully able to counter the climate change impact.

Welfare effects (Figs. 2–5) also show a similar trend. Welfare losses increase over time, and expectedly, the losses in general are lower if damages to agriculture are lower. Welfare effects are mainly driven by changes in factor and commodity prices (see Appendix 1 – Figs. A.1–A.5). The increase in fossil fuel prices (mainly coal prices because of higher emission factor compared to oil and gas) due to climate policy has an inflationary impact. Further, climate policy also leads to replacement of fossils fuels (mainly coal) by renewable energy and structural changes in the economy. The economy becomes relatively less energy intensive and more capital intensive under climate policy. Thus, climate policy leads to higher penetration of renewables in the total energy mix, and a shift towards less energy (mainly coal), but more capital intensive methods of production. Further, the simulations reveal that labor households[1] are more adversely affected than non-labor households (Fig. 5), in terms of welfare, under climate policy (SIM 4). Welfare gains are observed in SIM 4 during the initial years due to relatively lower carbon prices and recycling of carbon tax revenues for investments. Carbon prices increase significantly towards the end of the time horizon (late 2040's) and at

[1] Implies the following household groups - rural agricultural labor, rural other labor, urban salaried and urban casual labor. These groups derive a larger share of their income from wages.

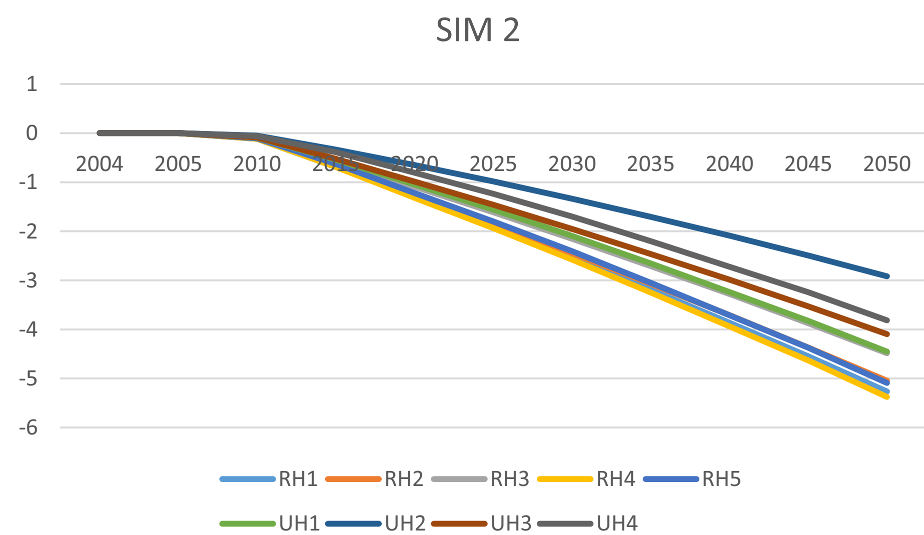

Fig. 3. Welfare impact (equivalent variation percent) for different household groups in SIM 2.
Source: Authors' estimates

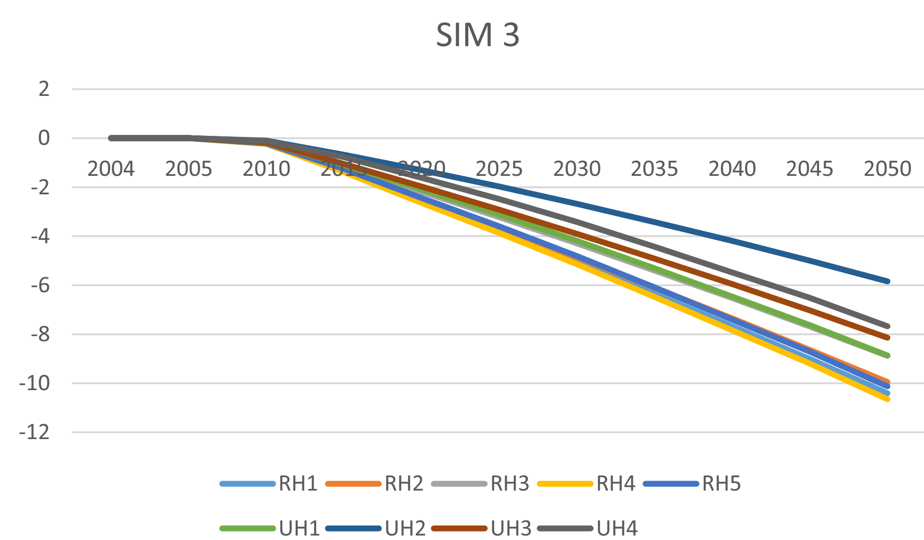

Fig. 4. Welfare impact (equivalent variation percent) for different household groups in SIM 3.
Source: Authors' estimates

these significantly higher carbon prices there is welfare loss. However, all households are almost equally affected (Figs. 2–4) in the productivity shock scenarios (SIM 1, 2 and 3). These results are observed because under climate policy there is price increase across the economy, while in case of productivity shocks there is relative price decline in case of all commodities except agriculture. In other words there are favorable terms of trade for fossil fuels (especially coal) under climate policy while there are favorable terms of trade for agriculture under productivity shock scenarios, however, this favorable terms of trade is not translated into higher real income of rural households in these scenarios. Price increase across the economy hurts labor households more than non-labor households. Also, the shift towards renewables and structural changes that occur under climate policy are likely to lessen the adverse effects on non-labor households because of higher capital mobility. In the presence of productivity shocks however higher agricultural prices are accompanied by lower demand (prices) in rest of the economy. Lower demand in the economy hurts non labor households more than labor households. A similar result has been reported by Hertel et al. (2010) who show that rise in food price in response to productivity shocks have the strongest adverse effects on non-agricultural, self-employed households and urban households. Higher agricultural prices due to productivity shocks do not translate into relatively better welfare outcomes for rural households in our study. In fact rural households suffer higher welfare losses relative to urban households under productivity shocks in our model, and this could be attributed to the fact that most of the rural households are net consumers of agricultural commodities and they spend a relatively larger share of their income on such commodities.

A comparison (Table 3) of the costs of agricultural productivity shocks with the cost of climate policy clearly reveals that climate policy is less expensive for the economy over the long run. The social cost of carbon, measured in terms of agricultural productivity loss, is estimated to be between 2 and 6 percent of GDP (zero percent discount rate), depending upon the magnitude of climate change impact. For interesting debates on the appropriate value of the discount rate the reader is referred to Nordhaus (2007) and Stern (2007). The estimated costs are comparable to Stern (2007) only if productivity shocks are assumed to be severe. Otherwise our estimates are lower than Stern (2007) according to whom the average cost to India is 6 percent of GDP. In this context it is

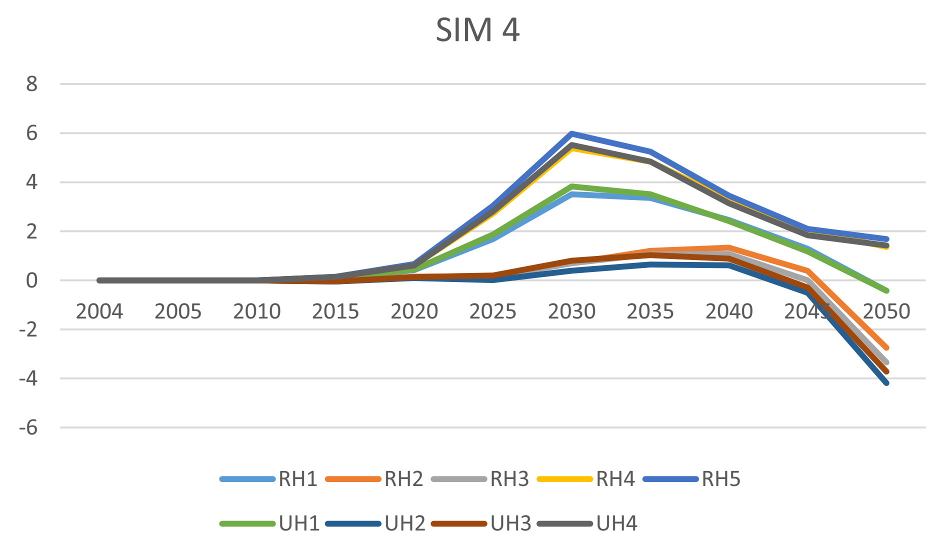

Fig. 5. Welfare impact (equivalent variation percent) for different household groups in SIM 4.
Source: Authors' estimates

Table 3
Comparison of costs of climate change and climate policy.

Simulation	Net Present Value of GDP (percent change relative to BAU) Discount rate: 0 percent	Net Present Value of GDP (percent change relative to BAU) Discount rate: 3 percent
SIM 1 (4.5 percent reduction in agricultural yield between 2010 and 2039)	−2.12	−1.80
SIM 2 (9 percent reduction in agricultural yield between 2010 and 2039)	−3.19	−2.71
SIM 3 (9 percent reduction in agricultural yield between 2010 and 2024)	−6.42	−5.45
SIM 4 (climate policy consistent with 2 °C global warming target)	−0.99	−0.59

Source: Authors' estimates

important to note that our estimates are based on only agricultural productivity losses, and assumptions about the magnitude of climate change, data, model etc also differ between the two studies. The cost of climate policy consistent with the 2 °C target, on the other hand, was found to be only 1 percent of GDP (zero percent discount rate). The estimated impacts are lower if a higher discount rate is assumed.

Thus, there is a strong case for the adoption of aggressive climate policy to reduce the level of emissions in order to sustain future growth in agriculture and in the economy. In particular, for countries like India with a huge population dependent on rain fed agriculture the long run benefits of climate policy are likely to be substantial. The selection and design of climate policy needs particular attention because some types of policies could benefit the economy more than others. Although the climate policy as modeled in this paper is a global carbon trading regime having limited relevance in the current context, nevertheless it shows that carbon pricing could be a viable tool for protecting the agriculture sector and the economy at large. It is hoped that decision makers realize the importance of pricing carbon for the conservation and efficient use of natural resources. The social cost of carbon as estimated in this paper does not include climate change induced costs on human health, ecosystems etc. The social cost of carbon is likely to be much higher if these costs are also included.

6. Conclusions and policy implications

The main objective of this paper was to compare the costs of climate change induced agricultural productivity shocks with the cost of climate policy consistent with the Paris Agreement global warming target of 2 °C for India. The social cost of carbon as measured by agricultural productivity loss, even as there are other associated losses, is higher than the cost of climate policy. Therefore, there is a strong case for the adoption of climate policy to reduce the level of emissions in order to protect the agriculture sector besides availing other positive externalities. The implementation of global agreements on reducing harmful emissions, such as the Paris Agreement, are of paramount importance in this context.

Our analysis shows that climate policy leads to overall price increase in the economy which hurts labor households more than non-labor households. Agricultural productivity shocks on the other hand affect non-labor households more than labor households due to lower demand. Productivity shocks are more widespread in the economy compared to climate policy and are therefore potentially more harmful. One way of reducing the costs would be to implement climate policy (carbon tax for example) and recycle the revenues for compensating the labor households, for the adoption of new technologies in energy and agriculture, and for augmenting capital formation in the economy. For example, subsidies for energy intensive methods of agricultural production could be reduced with the aim to promote sustainable agriculture in India. The recent thrust of the government to double farmers' income by 2022 is a very welcome step to reduce imbalances in income growth in the country. However, the policy makers should consider the crucial linkages between agricultural and climate/energy sectors while framing policies. Appropriately designed climate/energy policies could go a long way in protecting the agriculture sector from climate change induced shocks with minimal economic and environmental costs.

There is considerable scope for further research in this area in the context of public health, ecosystems etc.

Acknowledgement

We are very thankful to the anonymous referees for their useful comments.

Appendix A

Table A.1
GDP growth rate in the different scenarios (percent)

	BAU	SIM 1	SIM 2	SIM 3	SIM 4
2004–15	8.1	8.1	8.1	8.0	8.1
2015–20	8.3	8.2	8.1	8.0	8.3
2020–25	7.4	7.4	7.3	7.2	7.5
2025–30	6.9	6.8	6.7	6.6	6.9
2030–35	6.5	6.4	6.4	6.3	6.5
2035–40	6.4	6.3	6.2	6.1	6.3
2040–45	4.7	4.6	4.5	4.3	4.4
2045–50	4.3	4.2	4.2	4.0	3.1

Source: Authors' estimates

Table A.2
Household welfare in SIM 1 (equivalent variation percent)

	2015	2020	2025	2030	2035	2040	2045	2050
RH1	−0.46	−0.86	−1.27	−1.69	−2.13	−2.58	−3.04	−3.52
RH2	−0.45	−0.83	−1.23	−1.63	−2.05	−2.48	−2.92	−3.38
RH3	−0.39	−0.73	−1.08	−1.44	−1.81	−2.19	−2.59	−3.00
RH4	−0.46	−0.88	−1.29	−1.72	−2.17	−2.63	−3.10	−3.59
RH5	−0.42	−0.81	−1.20	−1.60	−2.03	−2.48	−2.92	−3.40
UH1	−0.36	−0.70	−1.04	−1.40	−1.77	−2.16	−2.55	−2.97
UH2	−0.22	−0.43	−0.66	−0.89	−1.14	−1.39	−1.66	−1.94
UH3	−0.35	−0.66	−0.97	−1.30	−1.64	−1.99	−2.36	−2.74
UH4	−0.26	−0.54	−0.82	−1.13	−1.46	−1.81	−2.16	−2.54

Source: Authors' estimates

Table A.3
Household welfare in SIM 2 (equivalent variation percent)

	2015	2020	2025	2030	2035	2040	2045	2050
RH1	−0.69	−1.29	−1.90	−2.54	−3.19	−3.86	−4.55	−5.27
RH2	−0.67	−1.25	−1.84	−2.45	−3.07	−3.71	−4.37	−5.05
RH3	−0.58	−1.09	−1.61	−2.15	−2.71	−3.28	−3.87	−4.48
RH4	−0.69	−1.32	−1.94	−2.58	−3.25	−3.94	−4.63	−5.38
RH5	−0.63	−1.22	−1.80	−2.41	−3.05	−3.71	−4.37	−5.09
UH1	−0.54	−1.05	−1.56	−2.09	−2.66	−3.24	−3.83	−4.45
UH2	−0.34	−0.65	−0.98	−1.34	−1.71	−2.09	−2.49	−2.92
UH3	−0.52	−0.99	−1.46	−1.95	−2.46	−2.99	−3.53	−4.10
UH4	−0.39	−0.80	−1.24	−1.70	−2.20	−2.72	−3.24	−3.82

Source: Authors' estimates

Table A.4
Household welfare in SIM 3 (equivalent variation percent)

	2015	2020	2025	2030	2035	2040	2045	2050
RH1	−1.38	−2.59	−3.80	−5.06	−6.35	−7.67	−9.01	−10.41
RH2	−1.34	−2.49	−3.67	−4.87	−6.10	−7.35	−8.64	−9.95
RH3	−1.17	−2.18	−3.22	−4.29	−5.40	−6.52	−7.68	−8.88
RH4	−1.38	−2.64	−3.87	−5.14	−6.47	−7.83	−9.20	−10.65
RH5	−1.25	−2.44	−3.60	−4.81	−6.09	−7.40	−8.71	−10.13
UH1	−1.08	−2.10	−3.12	−4.19	−5.31	−6.46	−7.63	−8.87
UH2	−0.68	−1.31	−1.97	−2.68	−3.42	−4.19	−5.00	−5.84
UH3	−1.05	−1.97	−2.92	−3.90	−4.92	−5.95	−7.03	−8.14
UH4	−0.77	−1.62	−2.49	−3.42	−4.43	−5.48	−6.52	−7.67

Source: Authors' estimates

Table A.5
Household welfare in SIM 4 (equivalent variation percent)

	2015	2020	2025	2030	2035	2040	2045	2050
RH1	0.06	0.42	1.68	3.51	3.36	2.46	1.29	−0.43
RH2	−0.04	0.15	0.17	0.70	1.20	1.33	0.39	−2.75
RH3	−0.05	0.13	0.15	0.70	1.06	1.07	0.00	−3.35
RH4	0.13	0.61	2.72	5.39	4.84	3.30	2.04	1.37
RH5	0.14	0.66	3.04	5.97	5.24	3.45	2.09	1.68
UH1	0.07	0.44	1.87	3.82	3.51	2.41	1.18	−0.42
UH2	−0.05	0.09	0.01	0.39	0.65	0.62	−0.51	−4.19
UH3	−0.04	0.13	0.20	0.80	1.03	0.89	−0.29	−3.72
UH4	0.14	0.61	2.81	5.52	4.84	3.14	1.84	1.42

Source: Authors' estimates

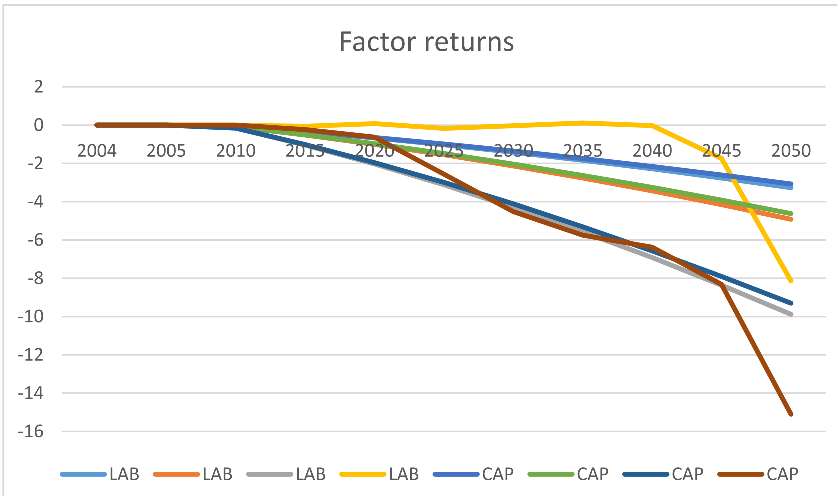

Fig. A.1. Returns to labour and capital in the different scenarios (percent change relative to BAU). Source: Authors' estimates.

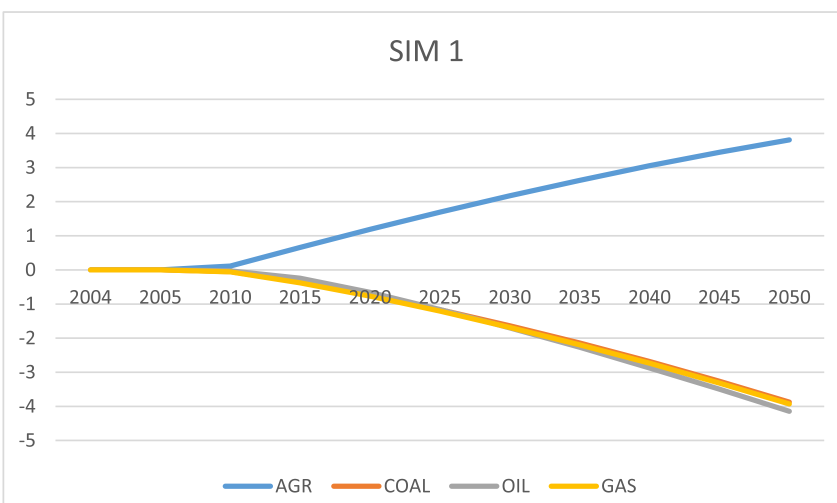

Fig. A.2. Effects on consumer prices in SIM 1 (percent change relative to BAU). Source: Authors' estimates.

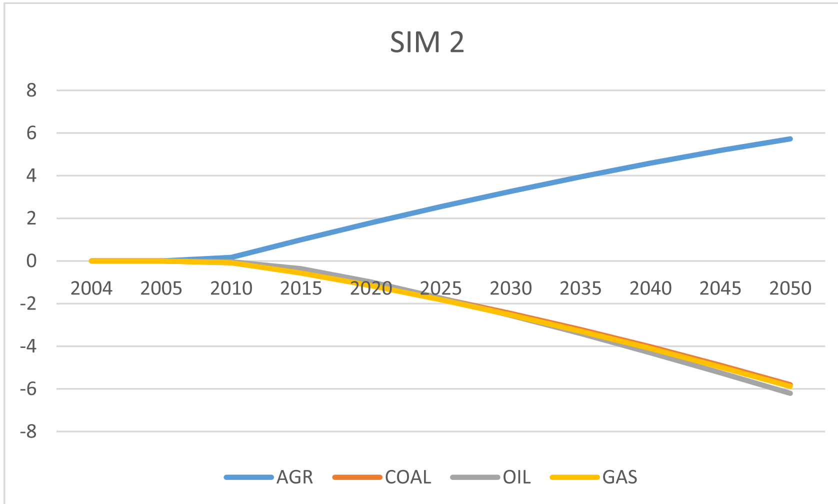

Fig. A.3. Effects on consumer prices in SIM 2 (percent change relative to BAU). Source: Authors' estimates.

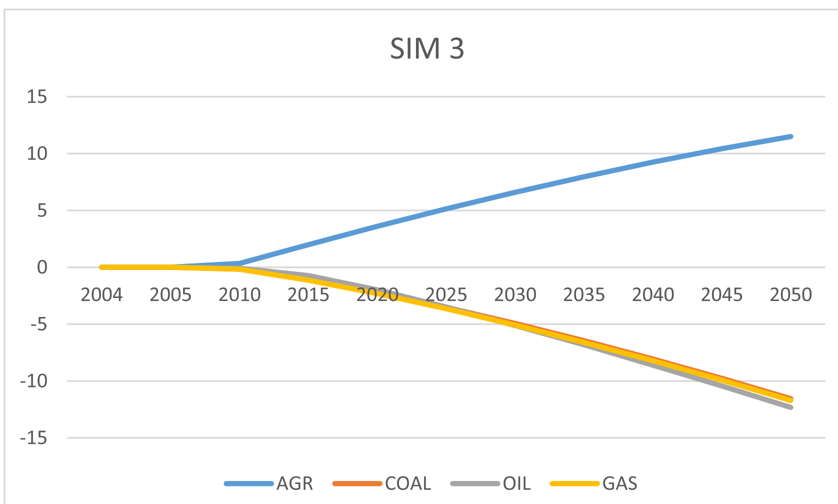

Fig. A.4. Effects on consumer prices in SIM 3 (percent change relative to BAU). Source: Authors' estimates.

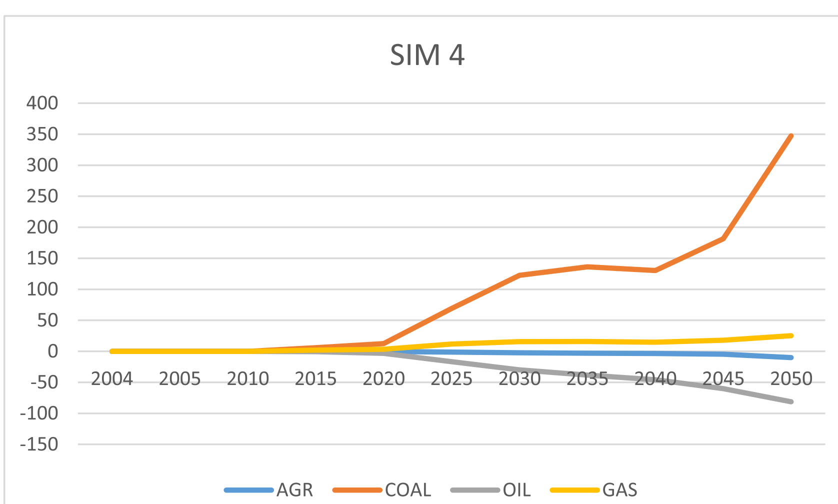

Fig. A.5. Effects on consumer prices in SIM 4 (percent change relative to BAU). Source: Authors' estimates.

Appendix B

Table B.1
Carbon prices and emission allowances for the climate policy scenario obtained from DART model

	2015	2020	2025	2030	2035	2040	2045	2050
Carbon price ($ per ton of CO_2)	1.9	6.8	34.7	71.1	107.2	145.7	222.4	440.8
Allowance (million tons of CO_2)	2316	2944	3589	4233	3997	3762	3526	3290

Appendix C

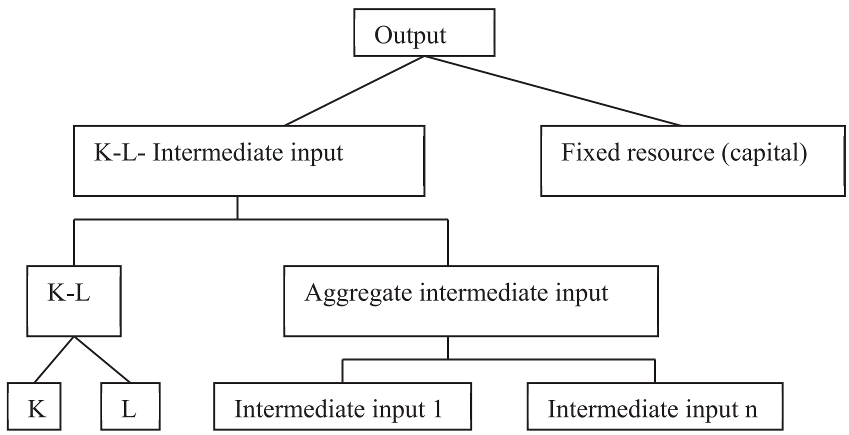

Fig. C.1. Production structure of fossil fuel sectors (coal, oil and gas).

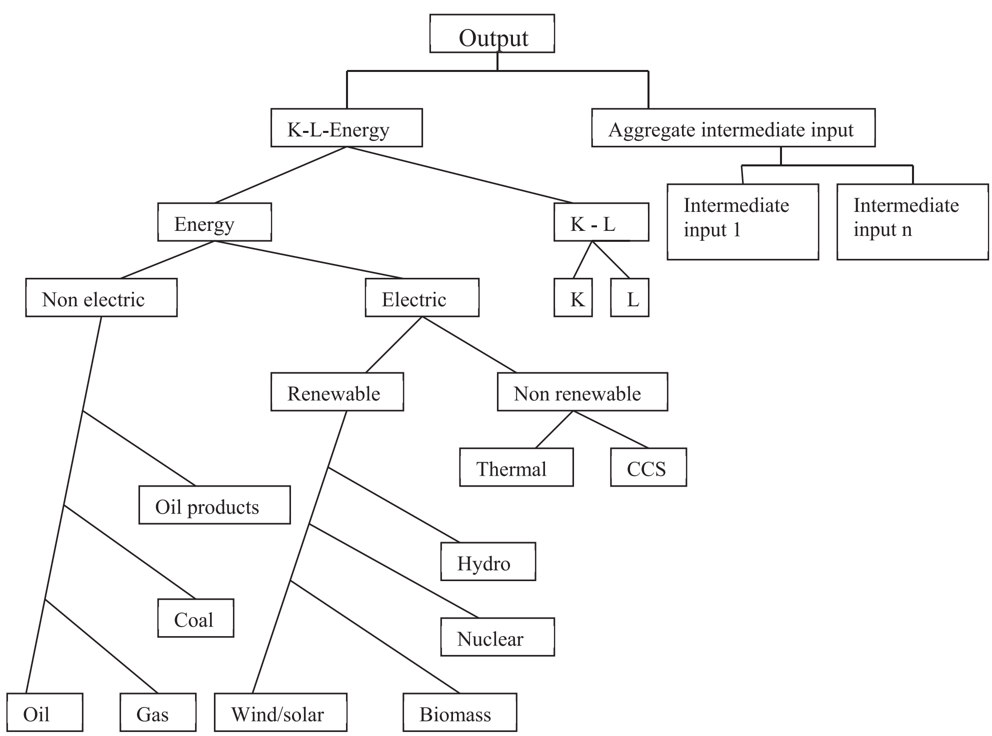

Fig. C.2. : Production structure of non-fossil fuel sectors.

Appendix D

Description of the basic structure of the CGE model (based on Pradhan and Ghosh, 2012)

D.1. Production module

The production module consists of labour, capital, energy and other intermediate inputs combining through a nested CES/Leontief function structure

to form sectoral output. In case of the fossil fuel sectors (coal, oil and gas), the top nest is a CES aggregation (see Equation (1)) of capital-–labour–aggregate intermediate input composite and the fixed fossil fuel resource (part of sectoral capital; captures the limited availability of fossil fuels in the economy).

$$QX(AF) = alphaa(AF)*\left(deltaa(AF)*QVAINTA(AF)^{-rhoa(AF)} + (1 - deltaa(AF))*QRES(RES, AF)^{-rhoa(AF)}\right)^{-1/rhoa(AF)} \quad (1)$$

where, QX(AF) is output of fossil fuel sector; alphaa (AF) shift parameter for CES production function for fixed resource sectors (between fixed resource and value added intermediate aggregate); deltaa(AF) share parameter for CES function for fixed resource sectors (between fixed resource and value added intermediate aggregate); QVAINTA(AF) is value added and intermediate input aggregate composite; rhoa (AF) CES function exponent for fixed resource sectors (between fixed resource and value added intermediate aggregate); QRES(RES,AF) is quantity of fixed resource.

The capital–labour–intermediate composite (see Equation (2)) is a Leontief function of the capital–labour composite and aggregate intermediate input.

$$QVAINTA(AF) = \min\left(\frac{QINT_{1,AF}}{\alpha_{1,AF}}, \frac{QINT_{2,AF}}{\alpha_{2,AF}}, \cdots, \frac{QINT_{n,AF}}{\alpha_{n,AF}}, \frac{QVA_{AF}}{\alpha_{QVA,AF}}\right) \quad (2)$$

where, QVAINTA (AF) is capital-labour-intermediate composite bundle for fossil fuel sector AF; $QINT_{j,AF}$ is intermediate input j for the fossil fuel sector AF; QVA_{AF} is aggregate value added for fossil fuel sector AF; $\alpha_{j,AF}$ is the direct requirement of sector AF on sector j per unit output of sector AF; $\alpha_{QVA,AF}$ is the direct requirement of sector AF on capital-labour composite per unit output of sector i.

The capital–labour composite (aggregate value added) is in turn a CES aggregation of capital and labour (see Equation (3)).

$$QVA(AF) = alphava(AF)*\left(deltava(F, AF)*QF(F, AF)^{-rhova(AF)} + \left(1–deltava(F, AF)*QF(F, AF)^{-rhova(AF)}\right)\right)^{-1/rhova(AF)} \quad (3)$$

where, QVA (AF) is quantity of aggregate value added; alphava (AF) shift parameter for CES function (between labour and capital); deltava (F, AF) share parameter for CES function (between labour and capital); QF (F, AF) quantity demanded of factor F from sector A; rhova (AF) is the CES production function exponent for value added.

In the case of non-fossil fuel sectors the top nest is a Leontief function of aggregate intermediate input and energy–capital–labour composite (see Equation (4)).

$$QX(ANF) = \min\left(\frac{QINT_{1,ANF}}{\alpha_{1,ANF}}, \frac{QINT_{2,ANF}}{\alpha_{2,ANF}}, \cdots, \frac{QINT_{n,ANF}}{\alpha_{n,ANF}}, \frac{QVAEN_{ANF}}{\alpha_{QVA,ANF}}\right) \quad (4)$$

where, QX (ANF) is output of non-fossil fuel sector; $QINT_{j,\ ANF}$ is intermediate input j for the non-fossil fuel sector ANF; QVAEN (ANF) is value added and energy composite for the non-fossil fuel sector; $\alpha_{j,ANF}$ is the direct requirement of sector ANF on sector j per unit output of sector ANF; $\alpha_{QVAEN,ANF}$ is the direct requirement of sector ANF on energy-capital-labour composite per unit output of sector ANF.

The energy–capital–labour composite is a CES function of the energy composite and capital–labour composite (see Equation (5)).

$$QVAEN(ANF) = alphavaen1(ANF)*\left(deltavaen1(ANF)*QVA(ANF)^{-rhovaen1(ANF)} + (1 - deltavaen1(ANF))*QEN(ANF)^{-rhovaen1(ANF)}\right)^{-\frac{1}{rhovaen1(ANF)}} \quad (5)$$

where, QVAEN (ANF) is QVAEN (ANF) is value added and energy composite for the non-fossil fuel sector; alphavaen1 (ANF) is shift parameter for CES function (between aggregate energy and aggregate value added); deltavaen1 (ANF) is share parameter for CES function (between aggregate energy and aggregate value added); QVA (ANF) is quantity of aggregate value added; rhovaen1 (ANF) is CES production function exponent (between aggregate energy and aggregate value added); QEN (ANF) is quantity of aggregate energy.

Similarly, the energy composite (QEN (ANF)) is a CES function of the non-electric composite and electric composite. The non-electric composite is a CES aggregation of coal, oil, gas, and oil products. The electric composite is a CES aggregation of renewable electricity composite and non-renewable electricity composite. The renewable electricity composite is a CES aggregation of hydro, nuclear, wind/solar and biomass electricity while the non-renewable electricity composite is a CES aggregation of thermal and CCS electricity. The capital–labour composite is a CES function of capital and labour.

D.2. Income and expenditure module

Household income and expenditure

Households maximize utility subject to income and prices, and the household demand for commodities is modeled through the LES as shown in Equation (6).

$$PQ(C)*QH(C, H) = PQ(C)*gammam\ (C, H)\ +\ betam(C, H)*\left(EH\ (H) - \sum_{C} PQ\ (C)*gammam\ (C, H)\right) \quad (6)$$

where, PQ(C) composite commodity price for C; QH(C, H) is quantity consumed of commodity C by household H; gammam (C, H) is per capita subsistence consumption of marketed commodity C for household H; betam (C, H) is marginal share of household consumption spending on commodity C; EH(H) is household consumption expenditure.

Household income comprises income derived from labour and capital and transfers from the government and the rest of the world (Equation (7)).

$$YI(H) = \sum_F YIF(H,F) + trnsfr(H,'GOVT')*CPI + trnsfr(H,'ROW')*EXR \tag{7}$$

where, YI (H) is income of household H; YIF (H, F) is income of household H from factor F; trnsfr (H,'GOVT') is transfers from government to household H; CPI is the consumer price index (numeraire); trnsfr (H,'ROW') is transfers from rest of the world to household H; EXR is the exchange rate.

Government income and expenditure

Government expenditure is on the consumption of goods and services, and transfers to households and enterprises (Equation (8)).

$$EG = \sum_C PQ(C)*QG(C,'GOVT') + \sum_H trnsfr\ (H,'GOVT')*CPI + trnsfr('PVTENT','GOVT')*CPI \tag{8}$$

where, EG is government expenditure; PQ(C) is composite price of commodity C; QG(C,'GOVT') is government consumption of commodity C; trnsfr (H,'GOVT') is transfers from government to household H; trnsfr ('PVTENT',' GOVT') is transfers from government to private enterprises.

Government income is from taxes (direct and indirect), capital, public and private enterprises, and the rest of the world. Indirect taxes include excise duty (production tax), import and export tariffs, sales, stamp, service, and other indirect taxes, including carbon tax (Equation (9)).

$$\begin{aligned}
YG = {} & \sum_H tins0(H)*YI(H) + \sum_A indtax(A,'texc')*PX(A)*QX(A) \\
& + \sum_C indtax(C,'tm')*pwm0(C)*QM(C)*EXR \\
& + \sum_C indtax(C,'tsal')*PQ(C)*QQ(C) \\
& + \sum_C indtax(C,'tstm')*PQ(C)*QQ(C) \\
& + \sum_C indtax(C,'toth')*PQ(C)*QQ(C) \\
& + \sum_C indtax(C,'tser')*PQ(C)*QQ(C) \\
& + \sum_C indtax(C,'te')*pwe0(C)*QE(C)*EXR + YIF('GOVT','Cap') \\
& + \sum_C YRES('GOVT','Res') + trnsfr('GOVT','PVTENT')*CPI \\
& + trnsfr('GOVT','ROW')*EXR \sum_C indtax(A,'tsub')*PX(A)*QX(A) \\
& \sum_{emm} pcarbon*emmfactor(emm)*QQ(emm) - QNEINT('Coal','ECCS') \\
& *emmfactor('Coal')*pcarbon
\end{aligned} \tag{9}$$

where, YG is government income; tins0 (H) is effective income tax rate paid by household H; YI(H) is income of household H; indtax (A,'texc') is effective excise duty rate; PX(A) is producer price for sector A; QX(A) is output of sector A; indtax (C,'tm') is import duty on commodity C; pwm0(C) is world import price for commodity C; QM(C) is quantity of imports of commodity C; EXR is the exchange rate; indtax (C,'tsal') is sales tax on commodity C; indtax (C,'tstm') is stamp duty on commodity C; indtax (C,'toth') is other taxes on commodity C; indtax (C,'tser') is service tax on commodity C; indtax (C,'te') is export tax on commodity C; PQ(C) is composite price of commodity C; QQ(C) is quantity of composite commodity C; pwe0(C) is world export price of commodity C; QE(C) is quantity of exports of commodity C; YIF('GOVT','CAP') is government income from capital; YRES ('GOVT',RES) is government income from fixed resources; trnsfr ('GOVT','PVTENT') is transfers from private enterprises to government; trnsfr ('GOVT','ROW') is transfers from rest of the world to government; indtax (A,'tsub') is effective production subsidy rate for sector A; pcarbon is the carbon price/tax; emmfactor (emm) is the emission factor associated with emitting sector emm; QQ (emm) is quantity of composite commodity for sector emm; QNEINT ('COAL','ECCS') is the quantity of intermediate input of coal in the ECCS sector.

D.3. Foreign trade module

We adopt the Armington specification (Equation (10)), and assume that domestically produced and imported goods are imperfect substitutes for each other. The Armington composite good is composed of the domestic good and imports following a CES function.

$$QQ(C) = alphaq(C)*\left(deltaq(C)*\ QM(C)^{-rhoq(C)} + (1 - deltaq(C))*QD(C)^{-rhoq(C)}\right)^{-1/rhoq(C)} \tag{10}$$

where, QQ(C) is the quantity of composite good C; alphaq(C) is Armington function shift parameter for commodity C; deltaq(C) is Armington function share parameter for commodity C; QM(C) is quantity of imports of commodity C; rhoq(C) is Armington function exponent for commodity C; QD(C) is quantity of domestic supply of domestic output.

The import demand function (Equation (11)), obtained from above, is shown below.

$$\mathrm{QM(C)} = \mathrm{QD(C)}*\left(\left(\frac{\mathrm{PDD(C)}}{\mathrm{PM(C)}}\right)*\left(\frac{\mathrm{deltaq(C)}}{(1-\mathrm{deltaq(C)})}\right)\right)^{1/(1+\mathrm{rhoq(C)})} \tag{11}$$

where, QM(C) is quantity of imports of commodity C; QD(C) is quantity of domestic supply of domestic output; PDD(C) is price of domestically produced

commodity C; PM(C) is import price of commodity C; deltaq(C) is Armington function share parameter for commodity C; rhoq(C) is Armington function exponent for commodity C.

As for exports, a CET function (Equation (12)) is adopted to allocate total domestic output between exports and domestic sales.

$$QX(C) = alphat(C)*\left(deltat(C)*QE(C)^{rhot(C)} + (1 - deltat(C))*QD(C)^{rhot(C)}\right)^{1/rhot(C)} \quad (12)$$

where, QX(C) is domestic production of commodity C; alphat (C) is CET function shift parameter for commodity C; deltat (C) is CET function share parameter for commodity C; QE(C) is quantity of exports of commodity C; QD(C) is quantity of domestic supply of domestic output; rhot(C) is CET function exponent for commodity C.

The export supply function (Equation (13)), based on the above is shown below.

$$\mathrm{QE(C)} = \mathrm{QD(C)}*\left(\left(\frac{\mathrm{PDD(C)}}{\mathrm{PE(C)}}\right)*\left(\frac{\mathrm{deltat(C)}}{(1-\mathrm{deltat(C)})}\right)\right)^{1/(\mathrm{rhot(C)}-1)} \quad (13)$$

where, QE(C) is quantity of exports of commodity C; QD(C) is quantity of domestic supply of domestic output; PDD(C) is price of domestically produced commodity C; PE(C) is export price of commodity C; deltat (C) is CET function share parameter for commodity C; rhot(C) is CET function exponent for commodity C.

D.4. Model closure

Regarding model closure, the main assumptions are exogenous government consumption; fixed foreign saving and flexible exchange rate and saving-driven closure. Further, full employment of capital and labour is assumed, and factor prices adjust to clear the factor markets.

D.5. Market clearing

Market clearing describes the equilibrium conditions in a CGE model. In the model market clearing refers to clearing of factor and commodity markets.

The market equilibrium equation for factor markets is shown below (Equation (14)). The supply of a factor equals the sum of demands from all sectors.

$$QFS(F) = \sum_{A} QF(F,A) \quad (14)$$

where, QFS (F) is the aggregate supply of factor (labour and capital); QF (F, A) is the quantity of factor F used by sector A.

The market equilibrium equation for commodity markets is shown below (Equation (15)). The quantity of composite good equals the sum of intermediate demand from sectors, household consumption demand, government consumption demand, and investment demand.

$$QQ(C) = \sum_{A} QINT(C,A) + \sum_{H} QH(C,H) + QG(C,'GOVT') + QINV(C) \quad (15)$$

where, QQ(C) is quantity of composite good; QINT(C,A) is intermediate demand for commodity C from sector A; QH(C) is quantity of household consumption of good C; QG(C, ‘GOVT’) is quantity of government consumption of commodity C; QINV(C) is quantity of investment demand for commodity C.

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